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Heat Stress Indices in the Hellenic Air Force (HAF)

Lt Ioannis Markou[1] MD, Maj. Ioannis Diamantopoulos[2] MD
Br.Gen. Evangelos Stathogiannis[3] MD, Br Gen Elias Chimonas[1] MD
1: HAF Center of Aviation Medicine (HAFCAM)
2: Office for Aviation Medicine, Preventive Medicine Division/ HAFGS Medical Directorate
3: HAF 251 General Hospital
251 HAFGH complex, 3 P. Kanelopoulou Str. Cholargos, Athens GR-115 25, Greece

SUMMARY

Introduction: Greece is characterized by very hot weather during summer. Since 1987, Hellenic Air Force (HAF) has adopted the Discomfort Index (DI) as its official heat stress index (HSI), nowadays considered as outdated.

Rationale: Because of the disadvantages that DI presents, a study was performed in order to examine the possible application of another heat stress index, more objective and accurate in predicting heat discomfort.

Materials and methods: For two months the Wet Bulb Globe Temperature (WBGT) index was calculated inside a bubble canopy (F-4) and a rotary wing (C-130) aircraft (WBGTa) as well as their respective runway WBGT data (WBGT ground, WBGTg). The same set of data was used to calculate Fighter Index of Thermal Stress (FITS) for the same time period. Flight log of four different AF Bases were accessed in order to determine the possible cancellations of flights due to Indices of Thermal Stress, as calculated.

Results: For the bubble canopy aircraft, the WBGTa may be considered equivalent to WBGTg because the aircraft remain on ground stand-by with canopies open. FITS value of 38 was found to be statistically equivalent of DI 28.6. Both were compared to DI currently in use.. On this basis, the number of flight cancellations due to WBGTa was limited by 77%, and by 99% due to FITS, as compared to cancellations due to DI. For the rotary wing aircraft, WBGTa and WBGTg were found in statistically significant correlation (t-test, paired, $p<0.0001$), therefore the former index may be used to predict the later.

Conclusions: The Discomfort Index (DI) may be replaced in the HAF as follows: For ground personnel, by the WBGT Index of thermal stress. For flying personnel, by WBGT for moderate or light work. For aircrew of airborne bubble canopy aircraft FITS (extended range) may be applicable, after elaboration for Mediterranean climatic conditions.

INTRODUCTION

Due to very hot and dry summer that characterizes Mediterranean type of climatic conditions, application of an objective and accurate heat index is a matter of safety either for flying or ground personnel.

Environmental factors, which are accepted as parameters in calculating heat stress, are dry (air) bulb temperature, humidity, air velocity and radiation (solar and infrared). Since 1987, Hellenic Air Force (HAF) utilize Discomfort Index **(1)** (DI) as their official heat index given by:

$$\mathbf{DI = T - 0.4\,(T-10) \times (1 - F/100)}, \qquad \text{(Equation 1)}$$

Where: “T” presents ambient temperature and “F” relative humidity.

When DI is reached 27 there is a recommendation for all non-essential flights to be cancelled and outdoor work regarding maintenance to be discontinued.

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They are disadvantages associated to the use of DI by military personnel:

1. DI is useful to provide general public with advice regarding heat stress and not military personnel in specific.
2. DI at its present form does not account for effects of radiant heat, a crucial environmental factor either during flight or groundwork, leading to impairment of aircrew performance, which may be further impaired by the "greenhouse effect" phenomenon **(2)** it precipitates.

The operational requirement for a new Heat Stress Index (HSI) included the following:

1. Accommodation of environmental factors, such as wind velocity, humidity and radiant heat.
2. Ease of use by untrained personnel (automatic calculation, if possible), based on readily available data, which should be easily read and interpreted in operational terms.
3. Significant correlation between ground weather data and personnel working conditions..
4. Task specific, thus able to assign values for both ground personnel and aircrew.

Aircrew working conditions were further categorized according to aircraft type: bubble canopy aircraft (e.g. fighters, helicopters) and large haul aircraft (e.g. C-130, etc)

As a result, a study was performed in order to determine possible ways of applying heat stress indices for ground personnel and aircrew according to work profile and aircraft type

MATERIALS AND METHODS

The following Heat Stress Indices were selected (further selection details in Discussion):

1. For ground personnel, the Wet Bulb Globe Temperature Index (WBGT) as described by Yaglou (1957).
2. For aircrew, the Fighter Index of Thermal Stress (FITS), as defined by Nunneley, (1979).

Meteorological data were prospectively acquired in four different HAF bases (110, 111, 112, 114 HAFB), for a period of two months each, in order to calculate WBGT and FITS values. All data were recorded between 10.00hrs and 19.00hrs daily for two consecutive months. The total testing period lasted several months (June- September 2001).

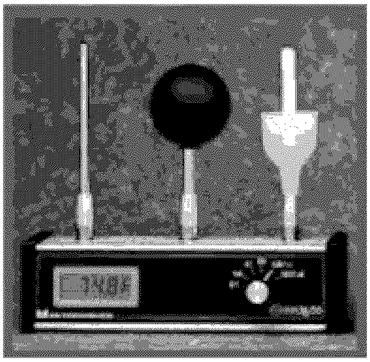

Figure 1: Heat Stress Monitor apparatus used (Metrosonic® HS 3600 heat stress monitor)

In particular, WBGT values were obtained automatically using a Metrosonics® HS 3600 Heat Stress Monitor equipped with a data logger. Two sets of devices were used simultaneously, the first based on ground (to serve as control data set) and the second inside an aircraft cockpit to enable correlation. The aircraft types included in the project were: McDonnel Douglas F-4, C-130 Hercules, Augusta Bell helicopter Type 205 and Super Puma.

Furthermore, meteorological data were pooled and flight logs of the same HAF bases were accessed and reviewed for period 1996- 2000 (all four years) in order to retrospectively calculate the WBGT and FITS values for the same bases at the respective time frame, and to determine their possible operational impact.

Because the regulations determine that whenever ambient temperature exceeds 30°C the canopy of aircrafts with bubble canopy remains open. Bear this in mind, measurements were made in the F4 aircraft cockpit and at the runway, near the aircraft, using Metrosonics® heat stress monitor, so as to estimate the relationship between the existing heat stress in the open cockpit and at the runway.

The same measurements were made in the cockpit of C-130 aircraft and AB-205 helicopter, in order to calculate, if possible, similar to FITS index.

RESULTS

WBGT values for ground measurements (WBGTg) and for aircraft measurements (WBGTa) were reviewed and mean values and standard deviations were calculated.(Table II). Statistical analysis was carried out using paired samples T-test The mean difference between the WBGT ground (WBGTg) and WBGT aircraft (WBGTa) is –1,11790 (SD: ±4,3468). The mean WBGTg correlated to WBGTa ($p<0,001$).

WBGT	Mean (^{0}C)	N	SD	STE Mean
WBGTg	28,2549	268	3,7161	,2270
WBGTa	29,4339	268	3,6745	,2245

Table I: Mean and SD for WBGT aircraft (WBGTa) and WBGT ground (WBGTg) measurements.

Restrictions posed to work activities (including flight schedule) is summarized for DI, WBGT and FITS in Table 2, according to individual established gradients, respectively.

Classification	DI	FITS	WBGT	
			Values	Recommendation for Restriction
Caution	N/A	32-38	28-29.3	Ground operations (preflight and cockpit stand by) limited to 90 min maximum. A minimum of 2 hrs for post flight recovery maintained.
Danger	N/A	**38**-46	29.4 - 31	All low level flights (landing practice, close support missions) cancelled. Ground operations limited to 45 min or less.
Cancellation	**> 27**	> 46	> 31	Cancellation of all nonessential flights

Table 2: Heat stress operational significance according to DI, FITS and WBGT. For example, WBGT Recommendation for Restrictions applicable for each stage is introduced.

For 110 HAF Base specifically, the operational impact on flight schedule is presented in Table 3.

Heat Stress Index	Caution	Danger	Cancellation	Comment
DI	N/A	N/A	145	Previously used HSi
WBGT	40	11	8	Reduction by 95.5%
FITS	446	19	1	Reduction by 99.7%

Table 3: Operational impact on flight OPS as determined by recommended action for each HSi for a specific HAF Base (110 HAFB).

DISCUSSION

The selection of Wet Bulb Globe Temperature **(3)** (WBGT) was based on its best fit into the criteria shown in Introduction. Thus, ease of use combined to automatic calculation (Metrosonics Heat Stress Monitor), simplicity, cost-effectiveness, and accounting for humidity, wind effects, temperature, radiant heat, and work type.
This may be shown in the WBGT Index calculation formula:

$$\mathbf{WBGT = 0.7\ T_{wb} + 0.2\ T_{bg} + 0.1\ T_{db},} \qquad \text{(Equation 2)}$$

where: "T_{wb}" = natural wet bulb temperature, "T_{bg}"= 150mm black globe temperature, And "T_{db}"= dry bulb temperature

Furthermore, Harrison et al (1979) **(5)** have shown correlation between WBGTa and WBGTg for the temperature range 16-25 ^{0}C, which may be extendable to hotter environments **(6)**.
Our results confirm the correlation between WBGTa and WBGTg in an expanded temperature range (13-39 ^{o}C).
Therefore, WBGT may serve as a reliable HSI for ground personnel and aircrew involved with ground activities. Likewise, HAF have ordered canopies open in case environmental temperature exceeds 30 ^{o}C, when fighter aircraft remain in ground stand-by mode, thus WBGTg may be used as a HSI.

For the rest of the bubble canopy aircraft (helicopters and fighters with closed cockpits), FITS was considered for application. The Fighter Index of Thermal Stress (FITS) developed at the USAF School of Aerospace Medicine by Nunneley and Stribley (4) provides a realistic guideline for insuring safe fighter operations in hot weather. FITS may be calculated as follows:

$$\mathbf{FITS = 0.83\ T_{pwb} + 0.35\ T_{db} + 5.08,} \qquad \text{(Equation 3)}$$

where: "T_{pwb}" = psychometric wet bulb temperature, and "T_{db}"= dry bulb temperature, both measured at ground level in ^{o}C.

	FITS Range			DI
	Caution	Danger	Cancellation	Cancellation
110 HAFB	75	33	1	35
114 HAFB	72	24	0	127
116 HAFB	87	28	0	107
120 ATW	84	34	0	101

Table 4: Operational impact of heat Stress in four HAF bases, as recommended by DI and FITS HSIs, respectively. Numbers refer to cancellations for the period 1996-1999 inclusive. Actual number of flights classified.

FITS chart is partly based on data correlating cockpit conditions to WBGTg. Any FITS application is based on the simplifying assumption that (4):

1. On clear days (full sun) Tbg, exceeds Tdb by 10 ^{o}C on both ground and cockpit,
2. Aircrew are in lightweight clothing, and
3. Their metabolism is 2 to 3 fold the resting values.

FITS is primarily designed to provide operational supervisors with an easily used guide to predictor of cockpit environmental conditions during low-level missions which may jeopardize aircrew performance.

However, the number of cancellations of flights due to FITS calculated retrospectively for the period 1996-1999 inclusive, show considerable tolerance (Tables 3and 4) to extremes of heat recorded during the same time frame, with respect to the ones after DI or WBGT application.

There may be several reasons for this discrepancy: Although WBGT and FITS are based on the same data, FITS does not account for black globe temperature, which presents radiant heat, a crucial element of the Mediterranean type of climatic conditions (Equations 1-3). Instead, FITS is based on the assumption that WGBTg will be different from WBGTa by 10 ^{o}C at least, which was not confirmed during this study accommodating temperature extremes reaching 39 ^{o}C and recorded during fully sunny days (main WBGTa-g difference was found: –1,11790 (SD: ±4,3468)). Likewise, the impact of air humidity is very low, due to the extremely dry conditions of the Mediterranean summer.
Retrospective calculations of FITS and DI for the period 1996-1999 have also shown a FITS value of 38 ^{o}C (when FITS flight restrictions start to apply) to be equivalent of a DI value of 28, thus resulting in a much looser criterion than the previously used DI value for flight cancellations, whose value was set to 27. Therefore, some work may be necessary to improve applicability of FITS to Mediterranean climate, specially when more protective clothing are considered for aircrew, further diminishing the efficiency of body heat loss mechanisms such as NBC protective ensembles.

The main concern of bubble canopy aircraft pilots concern their ground stand-by phase about possible detrimental effects on their flying performance. For fighter aircraft, open canopies may provide significant relief, since any accumulated heat is readily dissipated upon climbing to altitude. For helicopter application, Froom et al **(7)** have shown that the cooling effects of open cabin doors may reduce WBGTa below WBGTg values when WBGT exceeds 30 ^{o}C during an 1-hour ground stand-by mode. Therefore WBGTg values may be applicable as HIS during this sensitive phase.
With closed cockpit doors and canopies, WBGT ground values for heavy work could also be applied. For large haul aircraft, WBGTg values are again correlated to WBGTa and may serve as HSI.

CONCLUSION

This study has shown that Wet Bulb Globe Temperature Index (WBGT) ground values correlate to WBGT aircraft values in extended range, and WBGT may be used to predict heat stress in ground personnel and aircrew in large haul, of bubble canopy aircraft with cockpit doors or canopy open.
The Fighter Index of Thermal Stress (FITS) at its present form is not applicable on the bubble canopy aircraft with closed doors, and may require further adaptation to Mediterranean type of climatic conditions and to more complex aircrew ensembles.
Thermal stress on aircrew operating bubble canopy aircraft with closed canopies or doors performing exclusive low level – high speed mission may be predictable by WBGT ground values relating to heavy work.

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